Reaction Rates

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Introduction

The Collision Theory of Reactivity states that two conditions are needed for a chemical reaction to occur: 1) A sufficient level of energy (activation energy) and 2) The correct orientation of the particles in a reactant to allow maximum collisions (effective collisions). Five factors that affect reaction rates are surface area, temperature, concentration, nature of reactants, and the presence or absence of a catalyst. Some factors have an affect on the energy level of the molecules within the reactant, while others have an affect on the orientation and/or the number of collisions between particles of a reactant. Additionally, some of the factors affect both energy and orientation/collisions. The five factors are examined below, with respect to the Particle Model of Matter and/or Kinetic Molecular Theory.

1. Surface Area and Physical State of Reactant

One factor that affects reaction rates is surface area. Changing the surface area of a reactant will alter the amount of collisions and the orientation of the particles. The Particle Model of Matter and the Kinetic Molecular Theory both state that particles within a solid are tightly packed together and vibrate. Within solids, reactions happen at the surface of the reactant. If the surface area increases, faster reactions will occur as more of the reactant's molecules will be exposed and able to collide with particles of another substance. (see Appendix A)

The reaction of sodium and water is one example of how surface area affects reaction rates. If a large ball of sodium is placed in water, the reaction rate would be expected to be quite energetic and fast, but be slower than placing a similar volume of sodium powder in water. Since the sodium powder has a greater surface area, there are more opportunities for effective collisions to occur.

A second example of how surface area of a solid affects reaction rates can be seen in the effects of hydrochloric acid on iron. If an iron nail is placed in a tube of hydrochloric acid, the iron will slowly react and produce hydrogen gas. Alternatively, if you place a similar volume of iron powder in the same solution, the iron powder will react rapidly and produce more hydrogen bubbles. (see Appendix A)

2. Temperature

Temperature is another factor which affects reaction rates. At higher temperatures, particles have the opportunity to collide more frequently and with greater intensity. The Kinetic Molecular Theory states that energy causes particles to move and the greater the energy, the faster the particles move. Heat increases the energy level of particles causing particles to bump into each other more often. Also, heat can change the state of matter of a substance, from a solid to a liquid to a gas. As these substances heat up, the particles inside will become energized and have more opportunity for collisions. (see Appendix B)

One example where heat is used to increase reaction rates is the manufacturing of steel. Iron metal is made by heating iron oxide with carbon at a very high temperature. Since the particles are accelerated at a high speed, it takes less energy for them to collide together.

Another example is thermite, which is a mixture of aluminum powder (Al) and Iron Oxide (Fe_2O_3). When heat is added to the mixture, the oxygen atoms are freed from the iron and can be bonded with the aluminum instead, resulting in iron metal and aluminum oxide.

3. Concentration or pressure of reactant

A third factor that affects reaction rates is the concentration or pressure of a reactant. The Particle Model of Matter states that particles within gases have more space between each other compared to particles within solids. In addition, the Kinetic Molecular Theory states that gas particles are moving quickly and freely and have a lot of energy in comparison to liquids and solids. (see Appendix C)

Increasing the pressure of a gas increases its concentration. At a higher concentration, gas molecules have a higher density and are forced to be closer together. The higher concentration results in more collisions which cause reactions at a faster rate.

One example is the reaction between hydrochloric acid and zinc. A higher concentration of hydrochloric acid would result in the zinc reacting faster.

A second example is phosphorus. Phosphorus burns well in our air, but can react even more in an environment of pure oxygen.

4. Nature of reactants

Another factor of reaction rates is the nature of the reactants involved. Individual properties of the reactants can also affect reaction rates. Some of the properties that may have an effect on reaction rates are state of matter, molecular size, bond type and bond strength. The state of matter of a substance is a factor because different states react at various rates due to the arrangement of molecules. Gases tend to react faster than solids or liquids because as stated in the Kinetic Molecular Theory, gas particles move around quickly.

Similarly, molecule size, the number of bonds and type of bond of a substance can affect reaction rates. Reactions involving the breaking of fewer bonds react faster than reactants with multiple bonds. As well, substances that contain larger molecules tend to react slower.

One example is the burning of kerosene compared to the burning of methane. Kerosene burns slower than methane because there are more bonds to be broken per molecule of kerosene than there are per molecule of methane. Furthermore, kerosene is a bigger molecule. (see Appendix D)

Another example is the iron ion (Fe^{2+}). The simple ion Fe^{2+} reacts faster to oxygen than oxalate ($OOCCOO^{2-}$). The difference in reaction rates is due to the fact that oxalate has more bonds to be broken.

5. Presence or absence of a catalyst or inhibitor

A fifth factor that affects reaction rates is the presence or absence of a catalyst. A catalyst is a substance that accelerates a reaction by participating in it without being removed. Catalysts speed up reactions by lowering the activation energy required for a reaction. Conversely, an inhibitor slows down reactions instead of accelerating them. If a catalyst is present, the reacting particles can collide more successfully with less energy and so the reaction can take place at a lower temperature. However, a catalyst does not affect the energy of the reactant.

One technology that needs a catalyst to work is a hydrogen fuel cell. In the hydrogen fuel cell, hydrogen gas reacts with oxygen gas to make water and electricity. These systems can be found in a hydrogen vehicle where they create the electricity to power the engine. The fuel cell needs to separate the atoms in molecules of hydrogen and oxygen so that those atoms can combine to make new molecules (water). Without some assistance, combining those atoms would be very slow. So, the fuel cell uses a catalyst to speed up the reaction. (see Appendix E)

An example of an inhibitor are anti-rust sprays. Anti-rust sprays can be applied to metal surfaces to stop rust from forming and create a protective barrier that coats the surface and prevents further rust.

Key Definitions and Concepts:

Chemical Reaction

- A chemical reaction is a chemical change that occurs when chemical bonds between atoms are created or destroyed.

Particle Model of Matter:

1. All matter is made up of particles.
2. There are spaces between the particles that differ between different states of matter.
3. Particles are always moving.
4. Particles are attracted to one another.

Kinetic Molecular Theory

1. All matter is made up of particles.
2. There are spaces between the particles.
3. Particles are constantly moving.
    a. Solid particles are packed tightly and can only vibrate.
    b. Particles of a liquid are further apart and can slide past each other.
    c. Particles of a gas are far apart and can move around quickly.
4. Energy makes particles move, the more energy, the faster they move and the further apart they get.

Collision Theory of Reactivity

- Reactions happen when molecules of a reactant "effectively collide".

Effective Collision

- Molecules must have a minimum amount of kinetic energy (activation energy)
- Correct orientation

Surface Area of a Solid

- The matter in a solid physical state.

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